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S-702 - Rpt #14(Final)
Contract: QMRAE (MATICK) #2
(Agreement)
Swift and Company

The Effect of Sub-Sterilizing Doses of Cathode Rays and Gamma Rays on the Keeping Qualities of Pork

Period: 6 December 1954 - 1 January 1962

QUARTERMASTER FOOD AND CONTAINER INSTITUTE FOR THE ARMED FORCES
Research and Engineering Command
Quartermaster Corps, U.S. Army
Chicago, Illinois

CONTRACT RESEARCH PROJECT REPORT
QUARTERMASTER FOOD AND CONTAINER INSTITUTE
FOR THE ARMED FORCES, CHICAGO

HQ, QM RESEARCH AND ENGINEERING COMMAND
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Project No.: 7-84-01-002
Contract: QMR&D (Natick) No. 2
(No cost lease)
File No: S-702
Report #14 (Final)
Period: 6 Dec. 54 - 1 January 1962
Initiation Date: 6 Dec. 54

Title of Contract: The Effect of Sterilizing and Sub-sterilizing Doses of Cathode and Gamma Rays on the Properties of Beef and Pork

SUMMARY

In research on the irradiation of beef and pork, both at sterilizing levels and pasteurizing levels, the following were noted:

1. At pasteurizing levels, although bacterial population was reduced, the cooler shelf life of both pork and beef was not appreciably altered as compared with the control. In fact, color degradation appeared more rapidly in some instances in the irradiated samples.

2. A comparison was made wherein three different sources of radiation were used on beef steaks and pork chops at levels of 25,000 and 100,000 rads. The samples were irradiated in polyethylene bags and tested initially and after storage at 45°F. for flavor, tenderness and bacterial population. No differences in flavor or tenderness were noted between the control and irradiated samples. After one week at 45°F., all of the beef samples, including the controls, had a sour taste indicating that irradiation did not sufficiently protect this product. The pork samples held up somewhat longer; however, the controls held up as well as the irradiated product.

3. Affects of sterilizing doses on pork and beef from a gamma source and an 8 million volt linear accelerator were compared initially and after one, three and six months storage at 45°F., statistical analysis of strip steak mean flavor scores indicated that the control steaks were significantly better in flavor ($p < 0.01$) than the irradiated steaks at each storage time. The tenderness mean scores of the irradiated steaks were very significantly higher ($p < 0.01$) than the control steaks. There were no significant differences between the two types of irradiation.

4. A study was made wherein beef steaks were broiled to an internal temperature between 125°F. and 180°F. prior to gamma irradiation at 2.8M and 4.6M rads. Storage tests were made at 40°F. and 100°F. for periods up to six months:

   a. Ionizing irradiation reduced the bacterial population in all instances to less than 10 per gram.

   b. The flavor of all irradiated samples was markedly inferior to the non-irradiated controls. Precooking had little affect on the flavor scores. Those products irradiated at 4.6M rads were slightly inferior to those irradiated at 2.8M rads.

c. The aroma of all irradiated steaks was greatly inferior to that of the untreated frozen controls. Precooking or amount of irradiation had little affect on the average aroma scores.

d. Tenderness of all irradiated steaks was greater than that of the unirradiated controls. This was less noticeable in the case of steaks precooked at 180°F.

5. Samples of ground beef were mixed with alpha tocopherol, ascorbic acid and vitamin A prior to irradiation with gamma rays. This mixture masked some of the irradiation flavor. Heating at 140°F. for 16 hours either before or after irradiation had no particular affect on the flavor scores.

6. A reduction in irradiation flavor in beef steaks was accomplished by lowering the temperature substantially during irradiation. Irradiation at 4.5M rads at -196°C resulted in a product having little detectable irradiation flavor as scored by an expert panel. Meat frozen at other higher temperatures during irradiation had more irradiation flavor, but not as much as that irradiated at ambient temperature.

INTRODUCTION

Sub-sterilizing doses of both cathode ray irradiation and gamma ray irradiation were believed to be able to prolong the shelf life of commercial cuts of pork and beef. If the spoilage of cuts of beef are due to sub-surface bacteria as theorized, the keeping quality of meats treated with gamma rays should be greater than those treated with low energy cathode rays at the same irradiation level. Experiments were designed to compare the effects of cathode ray and gamma ray irradiation on the keeping qualities of beef under conditions usually found in commercial handling. The keeping quality was judged as to color, flavor and odor over an extended period of time.

Other objectives of this study were to ascertain the effects of sterilizing doses on beef steaks cooked at various temperatures from 125°F. to 180°F. prior to irradiation and how these samples stood up in storage; to compare steaks irradiated with a linear accelerator and with gamma rays; to determine whether or not tomato products reduced the irradiation flavor in beef by means of a protective action during radiation or by a masking action; and to determine the effect of extremely low (to -196°C) temperature irradiation on the flavor of irradiated beef steaks.

RESULTS AND DISCUSSION

Studies at Pasteurization Levels

Beef steaks were obtained from choice grade steer carcasses the second day after slaughter. Those used for gamma ray treatment were irradiated at Argonne National Laboratories at ambient temperature. For cathode ray irradiation a General Electric resonance transformer operating at 5×10^5 volts was used. This resulted in a maximum penetration of the surface to a depth of 0.1 mm. After irradiation, the steaks were assembled in 45°F. coolers and placed on display trays and overwrapped with polyethylene films in such a way as to entrap air over the samples. Such a method of handling insures the natural brightness and color of the meat and reduces the surface drying of the sample.

The steaks were tested for both color and flavor at various intervals. Irradiation was used at 2.3×10^4, 4.7×10^4, 9.3×10^4, 1.9×10^5, 4.7×10^5, 9.3×10^5, 1.9×10^6 rads.

Generally, the control samples were given an acceptable color grade through the first four days but deteriorated rapidly with time. The electron irradiated steaks showed initial good color only at the dose levels of 2.3×10^4 and 4.7×10^4 rads but were likewise unsatisfactory in four or five days. Samples receiving higher electron doses up to 1.9×10^6 rads were initially border line and deteriorated to an unsatisfactory product in four to five days. This deterioration manifested itself with the function of areas of grain of both the meat pigments and the fat tissue. On aging these areas increased until the entire sample was gray-green in color. The gamma irradiated samples exhibited the same general trend as were observed with the electron irradiated steaks; that is, the color of the steak pigment became more off-colored with increased irradiation. However, the gamma rays were more severe than were the cathode rays but did not form areas of green-gray as quickly as were seen in the electron irradiated steaks.

The results of taste panel tests for flavor were subjected to statistical analysis based on the individual panel mean flavor scores with three replications of both types of irradiation. The means for the various controls and treated combinations are given in Table I.

These results did not indicate that the cathode ray irradiation had significantly affected the flavor of the steaks. Gamma irradiation, however, resulted in very significant flavor deteriorations. It will further be noted that the extent of deterioration in the case of gamma irradiated meat was a function of the dose. Such was not observed for cathode irradiation. These findings can probably be explained by the fact that only the surfaces of the cathode ray irradiated steaks were irradiated whereas the gamma irradiated steaks were completely irradiated.

Odor evaluations were made and these disclosed that up to 9.3×10^4 rads no off odors due to irradiation could be detected. At 1.9×10^5 rads there was some question as to whether any odors due to irradiation could be

detected. At 4.7×10^5 rads and higher doses, irradiation odors could readily be detected.

Similar tests were run using pork instead of beef. The results of these tests were as follows. At doses under 9.3×10^4 rads cathode rays failed to extend appreciably the keeping time of pork. Above this level, however, sourness was retarded at a significant level. Gamma irradiation was found to be more effective than cathode radiation in retarding spoilage at the lower dose levels, but at the same time it produced more organoleptic damage. While ionizing irradiations deteriorated the color of pork to some extent, the effect was by no means as great as that observed in beef. Moreover, the extent of the deterioration appeared to be a function of dose level.

Effect of Cooking Steaks Prior to Irradiation

Steaks from boneless rib eye beef were cooked to an internal temperature of 125-180°F. and placed one each in #3 cans, sealed under vacuum and irradiated with gamma rays at 2.8 M and 4.6 M rads. Samples of the steaks were stored at 40°F. and 100°F. for periods up to six months. Flavor, aroma and tenderness scores are given in Tables II, III and IV.

All samples had a bacteria population of less than 10 per gram, both immediately after irradiation and after storage at 40°F. and at 100°F. This was true for irradiation at 2.8 M and 4.6 M rads.

The color of the precooked steaks immediately after irradiation was quite pink all the way through the meat except for those steaks that were broiled to 180°F. which had some gray areas. The raw steaks were red all the way through and these observations were true at all storage intervals. In the case of the steaks that were broiled after irradiation, the interior of the steaks was also pink when freshly sliced. After cutting the pinkness faded to gray very rapidly.

From the results in Table II it is seen that the steaks treated at 4.6 M rads have more irradiation flavor than those treated with 2.8 M rads.

In Table III the aroma scores of the irradiated steaks after cooking are tabulated. It is seen that the irradiated steaks had much poorer aroma than the unirradiated. Precooking had little effect on the aroma scores.

Tenderness scores from Table IV show that irradiation caused tenderness in all samples except possibly those cooked at 180°F. prior to irradiation. At this temperature it is possible that because of the dryness it was not possible to recognize the tendering if it were present or perhaps the meat was not tender because of coagulation prior to irradiation.

Comparison of Radiation Sources

A direct comparison was made:

a) Between gamma irradiation and 8 million volt electrons from a linear accelerator at sterilizing doses (5 million rads) for pork and beef.

b) Between gamma irradiation, 0.8 million volt electrons from a resonance transformer and 8 million volt electrons from a linear accelerator at pasteurizing doses (25,000 and 100,000 rads). Paired beef loins and paired pork loins were secured, cut into strip steaks and pork chops respectively. The steaks and chops from three pairs of loins were packaged in vacuum in Saran coated cellophane which had been coated with 2 mils of polyethylene. These samples were used for the sterilizing test and controls. Two other loins from both the beef and the pork were packaged in polyethylene. These were used for the pasteurizing tests. Samples were taken to the linear accelerator at the W. F. and John Barnes in Rockford, Illinois for irradiation. Other samples were taken to Argonne National Laboratories in Lemont, Illinois for gamma radiation and the rest were irradiated with the Swift resonance transformer.

After irradiation, all samples were stored at 45°F. Inspection for bacteria, flavor and tenderness were made after 0, 1, 3 and 6 months storage. The results for flavor and tenderness are shown in Tables V, VI, VII and VIII attached. All irradiation sterilized samples had a bacteria population of less than 10 per gram, both immediately after irradiation and after 1, 3, and 6 months storage at 45°F.

Statistical analysis of the flavor scores from both steaks and chops indicated the control samples were significantly better in flavor than the irradiated samples ($p < 0.01$). The steaks irradiated with the linear accelerator scored somewhat higher than those irradiated with gamma rays. This difference was not significant ($p < 0.05$). There were no significant differences between the flavor scores of the pork chops irradiated by the two methods.

Tenderness evaluation showed that the irradiated samples were very significantly more tender ($p < 0.01$) than the control samples. No significant differences were noted between the two types of irradiation.

In the case of the pasteurized samples, bacterial examinations were made initially and after storage at 45°F.. In the case of beef, the initial bacteria populations were somewhat high and were reduced significantly by irradiation in the majority of the samples. The fact that all counts were high after one week at 45°F., and the fact that all of the samples had a sour odor and flavor after one week indicates that in this instance irradiation at 25,000 or 100,000 rads did not increase shelf life significantly. The bacteria populations of the pork chops were quite low initially and were reduced in all instances by irradiation.

However, after one week at 45°F. storage many of the counts were high but no sour flavors or odors were noted.

The results of taste panel tests on these samples are shown in Table IX. The initial flavor scores indicated that there were only slight differences between the flavor of the product treated at 25,000 or 100,000 rads by any of the three sources. The beef steaks were sour and therefore, poor after storage for one week at 45°F.

Tenderness evaluations were made at the same time with no appreciable tendering noted by irradiation with 25,000 or 100,000 rads by any of the sources.

Additives with a Tomato-Like Base

It has been reported that certain additives, including some vitamins were beneficial in preventing the detection of irradiation flavors in beef. Samples of ground beef were prepared with alpha tocopherol, ascorbic acid and vitamin A mixed on the basis of 0.18 gram of alpha tocopherol, 0.15 gram ascorbic acid and 0.06 grams vitamin A per pound of meat. A second lot of meat was prepared containing no additive and a third lot of meat prepared containing a ten-fold amount of the additive. Samples from each of these three lots were sealed under vacuum in a transparent bag. Some samples were heated overnight at 140°F. and then irradiated at 4.8 M rads. Others were irradiated at 4.8 M rads and then heated overnight at 140°F. and a third set of samples were irradiated at 4.8 M rads with no heat. Irradiation was done with gamma rays at Argonne National Laboratories. All samples were cooked and evaluated for flavor as shown in Table X.

It is seen that much less irradiated flavor was detected in those samples having the additive regardless of amount. Heat before and after irradiation had no apparent affect upon the flavor scores. It is indicated that this lower irradiated flavor is accomplished by a masking rather than a preventative action.

Low Temperature Irradiation

It has been observed that steaks irradiated at reduced temperatures result in less irradiation flavor than those treated at room temperature. Some preliminary work was done to investigate the effect of irradiation at low temperature upon the flavor of beef steaks. These steaks were enzyme inactivated at about 160°F. internal temperature and then placed in cans and irradiated at various temperatures from ambient to -196°C. Flavor scores from this irradiation are shown in Table XI.

It is seen that much less irradiation flavor was detected in the sample irradiated at a -196°C. than at higher temperatures. More irradiation flavor was found at the other frozen temperatures, still more at 0 and most at +20°C.

Table I

Mean Flavor Scores* of Irradiated Beef

Amount of Irradiation	Control	Cathode Ray	Gamma Ray
2.3×10^4 rads	8.1	7.7	6.3
4.7×10^4 "	6.8	6.7	5.3
9.3×10^4 "	6.8	6.6	4.7
1.9×10^5 "	7.1	7.3	6.8
4.7×10^5 "	7.2	7.1	6.1
9.3×10^5 "	7.2	7.0	5.6
1.9×10^6 "	7.2	7.1	5.0

* Based On:

10	Excellent	5	Fair
9	Good +	4	Fair -
8	Good	3	Poor +
7	Good -	2	Poor -
6	Fair +	1	Repulsive

Table II

Flavor Scores* of Pre-cooked Beef Steaks - After Irradiation

	2.8M Rads						4.6M Rads					
MONTHS at 40°F.	0	1	2	4	6	Av.	0	1	2	4	6	Av.
PRECOOK TEMP °F												
Raw	3.0	2.6	2.3	2.3	2.3	2.5	2.0	2.3	3.0	1.5	3.3	2.4
125	3.8	3.5	3.5	4.0	3.1	3.6	3.9	3.0	2.7	4.0	3.6	3.4
140	5.0	3.8	4.0	3.7	3.0	3.9	2.9	2.8	2.7	3.7	2.9	3.0
155	5.7	3.2	3.3	3.7	4.0	3.8	4.1	2.8	4.0	3.9	3.9	3.7
165	4.2	4.3	3.3	4.0	4.0	4.0	3.3	2.8	3.9	4.2	3.8	3.6
180	3.5	3.7	2.5	3.7	3.6	3.4	3.7	2.2	3.7	3.7	3.4	3.3
Av.	4.2	3.0	3.2	3.6	3.3	3.5	3.3	2.5	3.3	3.5	3.7	3.3
Std.	9.0	8.0	8.0	9.0	8.0	8.4	9.0	8.0	8.0	8.0	7.0	8.0

* Based on same scale as shown in Table I.

Table III

Aroma Scores* of Pre-cooked Beef Steaks - After Irradiation

MONTHS at 40°F.	2.8M Rads						4.6M Rads					
	0	1	2	4	6	Av.	0	1	2	4	6	Av.
PRECOOK TEMP °F.												
Raw	4.0	3.2	3.2	1.8	5.3	3.5	4.0	2.2	3.2	1.3	1.8	2.5
125	3.7	3.2	4.0	3.7	5.3	4.0	4.3	3.7	1.7	3.3	3.4	3.3
140	2.0	4.2	4.2	3.3	4.3	3.6	3.7	3.7	3.2	3.2	3.4	3.4
155	4.2	3.7	3.6	3.5	4.8	4.0	5.0	2.7	3.0	3.0	3.9	3.5
165	4.0	3.7	3.8	3.0	4.6	4.0	4.4	2.7	3.0	2.3	4.3	3.3
180	3.9	3.5	4.0	3.7	4.6	4.0	4.6	2.2	3.7	2.8	3.4	3.3
Av.	3.6	3.6	3.8	3.2	4.9	3.9	4.3	2.9	3.0	2.7	3.5	3.3
Std.	10.0	9.0	9.0	9.0	9.0	9.2	10.0	8.0	9.0	9.0	8.0	8.8

* Based on same scale as shown in Table I.

Table IV

Tenderness Scores* of Pre-Cooked Beef Steaks - After Irradiation

MONTHS at 40°F.	2.8M Rads						4.6M Rads					
	0	1	2	4	6	Av.	0	1	2	4	6	Av.
PRECOOK TEMP °F.												
Raw	5.5	6.3	5.3	5.2	8.5	6.2	10.0	8.3	6.6	8.6	8.5	8.4
125	6.5	6.8	5.3	6.7	7.4	6.5	9.7	7.0	8.1	9.3	8.8	8.6
140	8.3	7.5	8.6	5.5	8.9	7.8	8.3	7.5	7.1	9.2	8.8	8.2
155	8.3	7.8	7.8	7.3	8.0	7.8	9.0	7.5	4.7	8.0	8.9	7.6
165	5.7	5.2	7.5	5.0	5.5	5.8	9.3	7.2	8.6	6.5	7.4	7.8
180	6.7	3.8	5.0	5.0	6.4	5.4	4.9	5.7	4.9	6.5	5.5	5.5
Av.	6.8	6.2	6.6	5.8	7.4	6.6	8.5	7.2	6.7	8.0	8.0	7.7
Std.	4.0	4.0	5.0	4.0	4.0	4.2	4.0	5.0	5.0	5.0	5.0	4.8

* Based on same scale as shown in Table I.

Table V

Flavor Scores* of Control and Irradiated Beef Steaks

Months Storage at 40° F.	Animal No.	Control	Gamma	Linear Accelerator
0	1	3.86	1.71	2.00
	2	4.14	1.86	1.86
	3	4.28	1.43	1.43
	Av.	4.09	1.67	1.76
1	1	4.00	1.00	1.17
	2	4.00	1.40	1.50
	3	4.20	1.20	1.80
	Av.	4.06	1.20	1.49
3	1	4.20	1.00	1.20
	2	4.00	1.60	1.80
	3	4.00	1.20	1.80
	Av.	4.07	1.27	1.60
6	1	4.43	1.53	1.86
	2	3.14	2.33	2.17
	3	4.00	1.00	2.02
	Av.	3.86	1.62	2.02

*Based on comparison with reference standard:

5 Better
4 Not different
3 Slightly poorer
2 Poorer
1 Much Poorer

TABLE VI

Flavor Scores* of Control and Irradiated Pork Chops.

Months Storage at 40°F.	Animal Number	Control	Gamma	Linear Accelerator
0	1	4.00	2.58	2.00
	2	3.71	1.58	1.71
	3	4.14	2.58	2.57
	Av.	3.95	2.24	2.09
1	1	4.00	1.67	1.67
	2	3.50	1.50	1.40
	3	3.60	1.40	1.60
	Av.	3.70	1.52	1.56
3	1	4.00	1.83	1.83
	2	4.00	1.33	2.00
	3	3.67	1.83	1.67
	Av.	3.89	1.66	1.83
6	1	4.00	2.17	1.75
	2	3.83	2.28	1.82
	3	4.00	2.40	2.67
	Av.	3.94	2.28	2.08

*Based on same scale as Table V.

TABLE VII

Tenderness Scores* of Control and Irradiated Beef Steaks

Months Storage at 40°F.	Animal Number	Control	Gamma	Linear Accelerator
0	1	6.00	7.85	8.28
	2	5.28	6.71	6.57
	3	6.00	7.85	7.71
	Av.	5.78	7.47	7.52
1	1	7.17	9.17	9.17
	2	5.50	8.00	8.84
	3	6.60	8.40	8.20
	Av.	6.42	8.52	8.74
3	1	5.25	9.50	9.00
	2	7.20	9.40	8.50
	3	7.00	9.60	9.60
	Av.	6.48	9.50	9.03
6	1	6.17	9.67	8.83
	2	6.00	8.00	8.33
	3	7.00	8.67	8.58
	Av.	6.39	8.78	8.58

* Based on same scale as Table I.

TABLE VIII

Tenderness Scores* of Control and Irradiated Pork Chops

Months Storage at 40°F.	Animal Number	Control	Gamma	Linear Accelerator
0	1	7.85	9.28	9.14
	2	7.57	7.85	8.14
	3	6.71	7.57	7.71
	Av.	7.37	8.23	8.33
1	1	8.00	9.33	10.00
	2	7.50	9.00	8.80
	3	5.40	7.80	7.20
	Av.	6.97	8.71	8.67
3	1	9.17	9.17	9.84
	2	6.47	9.50	8.84
	3	7.67	8.67	9.34
	Av.	7.77	9.11	9.34
6	1	9.00	9.84	9.40
	2	7.47	8.90	9.80
	3	7.80	8.00	7.00
	Av.	8.09	8.91	8.73

* Based on same scale as Table I.

TABLE IX

FLAVOR SCORES OF IRRADIATED PASTEURIZED MEATS
(AS SCORE OF 2 ANIMALS)

	GAMMA		LINEAR ACCELERATOR		RESONANT TRANSFORMER	
RADS	25,000	100,000	25,000	100,000	25,000	100,000
Beef Steaks						
Initial	3.19	3.44	3.38	3.25	3.31	3.50
1 Week at 45°F.	1.33	1.33	1.33	1.17	1.83	1.00
Pork Chops						
Initial	3.90	3.52	3.94	3.68	3.92	4.10
1 Week at 45°F.	3.28	3.20	3.14	3.15	3.30	3.01

Scores based on:

5 Excellent
4 Good
3 Fair
2 Poor
1 Very Poor

TABLE X

AMOUNT OF IRRADIATION FLAVOR* IN GROUND BEEF

	No Additive	Additive	
		Normal Amount**	10 X Normal
No heat	4.7	2.5	2.3
Irradiated, then heated	4.5	1.8	2.0
Heated, then irradiated	5.2	2.2	2.7
Avg.	4.8	2.2	2.3

*Based on:
1 None
2 Very little
3 Little
4 Moderate
5 Much
6 Very Much

**formula:
0.04% α-tocopherol
0.033 ascorbic acid
0.013 Vitamin A

TABLE XI

IRRADIATION INTENSITY SCORES OF BEEF STEAKS
Irradiated at 4.5M Rads at Various Temperatures

Irradiation Temp. °C.	Irradiation Intensity Scores*
Control (no irradiation)	1.08
-196	2.18
-170 to 0 during irradiation	3.33
-75	3.41
-30	3.33
0	4.16
+20	6.25

* Based on:

1 None

3 Slight

5 Moderate

7 Strong

9 Extreme